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Minimising Side Effects of Virtual Environments

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ABSTRACT

For some individuals participation in virtual environments (VEs) can result in side effects, including symptoms of nausea, disorientation, postural instability or eyestrain. The incidence and severity of symptoms are influenced by a number of factors related to the design of the VE, the task being performed, and the susceptibility of the participant. Thus taking these factors into account when designing the VE and tasks, and specifying what is required of participants, can reduce side effects. This report lists the relevant factors, and makes general recommendations to ensure that side effects in VEs are avoided or minimised. Particular consideration is given to the wide screen display of the Future Operations Centre Analysis Laboratory (FOCAL), where factors needing empirical investigation are identified.

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Minimising Side Effects of Virtual Environments

Executive Summary

Virtual environment (VE) technology has the potential for innovative applications within Defence. One new facility being used to explore such applications is the Future Operations Centre Analysis Laboratory (FOCAL). However, progress with any VE technology may be hampered by the side effects experienced by some participants. These side effects can include the motion-sickness-like symptoms of nausea and postural instability, as well as visual symptoms such as blurred vision or eyestrain. The occurrence and severity of these side effects are influenced by a number of factors related to the design of the VE and the tasks to be performed in it. They are also influenced by the susceptibility of individual participants. Thus taking these factors into account during design of the VE and associated tasks, and consideration of the demands to be placed on individual participants, can thereby avoid or minimise such side effects.

This report lists factors that can influence side effects, and makes general recommendations to reduce the incidence or severity of side effects in VEs. Recommendations are made for the design of the VE, for the tasks to be carried out, and for the requirements on the individual participants. Those factors relevant to the wide screen display of FOCAL are identified, and in some cases more specific recommendations are made. The effects of a number of factors have yet to be determined, and empirical research is needed to give specific recommendations on how these should be handled.

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1. Introduction

Participation in virtual environments (VEs), by viewing displays generated on virtual reality (VR) systems, can induce side effects in susceptible individuals. These side effects are experienced as symptoms of sickness, disorientation, instability, or eyestrain, and may occur during or after participation. Not everyone is likely to be affected, and not all VEs induce side effects. With the establishment of the Future Operations Centre Analysis Laboratory (FOCAL) a variety of VEs, from battlespace displays to complex visualisations, will be generated. It is therefore timely to raise issues that should be considered during the design of displays or VEs in order that side effects be avoided or at least minimised.

The VR systems available today are a diverse group, capable of generating a wide variety of VEs. Although in the past the terms "virtual reality" and "virtual environment" have been used somewhat loosely, most writers in the field now use the term "virtual reality" to apply to those systems used to generate "virtual environments" to be experienced by participants. The resulting VEs may be characterised by a number of properties: they are computer generated, interactive in real time, immersive, allow intuitive interaction and navigation, generate feelings of presence or involvement, and may display objects as 3-dimensional (3D). Not all VEs have all these properties, although all are computer generated and real-time interactive. For example, some VEs are not fully immersive, or some may not generate a sense of presence. However, they are still capable of causing side effects.

It is not possible at the present time to specify conditions that would guarantee that all side effects would be avoided for an environment generated by a particular VR system. Firstly, it might not be possible to eliminate side effects totally. Secondly, VR systems are so diverse, and the technology has developed so rapidly, that predictions based on studies of environments on other systems are difficult. Thirdly, individual users differ greatly in susceptibility. Thus whether particular symptoms will be problematic for a VE on a given system remains an empirical question to be investigated. This report merely raises the issues that should be considered when designing a VE. For a detailed account of the research on side effects see Barrett [2003].

2. Cybersickness: The Side Effects of Virtual Environments

The unintended psychophysiological side effects of exposure to VEs are usually referred to as cybersickness. Previously they were often termed simulator sickness, due to the similarity to side effects experienced in flight simulators.

2.1 Symptoms and Dimensions of Cybersickness

The symptoms of cybersickness have been grouped into three dimensions: nausea, postural instability, and oculomotor effects.

2.1.1 Nausea

The symptoms grouped under the dimension of nausea can include nausea, general stomach discomfort, burping, increased salivation, pallor, sweating, difficulty concentrating, and fatigue or drowsiness. Although actual vomiting or even extreme nausea is rare, the symptoms can be sufficiently severe as to cause participants to withdraw.

Nausea is a subjective symptom, and is usually assessed by the participant's own self-report or by questionnaire. The more objective signs such as pallor are usually preceded by subjectively experienced discomfort, at which time the participant should take time out from the environment.

2.1.2 Postural instability

Postural instability may be manifested as disorientation, dizziness, and/or unsteadiness in standing or walking. Instability may be associated with nausea, or may occur alone. It may also persist for some time after exposure to the VE.

Postural instability has also been measured by self-report or questionnaire. However, because individuals can be poor judges of their own instability, and because it poses a safety risk both to them and others should they undertake activities such as driving before they have fully recovered, it is better assessed by objective tests. Among the most reliable objective tests are simple static posture tests.

2.1.3 Oculomotor effects

Visual symptoms include eyestrain, headache, blurred or double vision, and difficulty focussing. The symptoms most commonly occur while viewing stereoscopic displays, and can be associated with measurable physiological changes in the resting vergence angle of the eyes. Depending on the display viewed, these changes may be either exophoric (eyes turned outwards) or esophoric (eyes turned inwards), and are associated with decreased visual acuity and reduced perception of stereoscopic depth cues. Symptoms can occur even after a relatively brief exposure to a stereoscopic display, but then are relatively short-lived after leaving the VE.

These symptoms have also been measured subjectively as reports of eyestrain, or by questionnaire, and subjective symptoms have been found to correlate well with physiological changes. They can also be assessed using simple orthoptic tests.

2.2 When Cybersickness Symptoms Occur

The most obvious symptoms are those that occur during exposure to the VE. Depending on the susceptibility of the individual, symptoms can begin shortly after exposure commences and will usually increase with duration of exposure. Longer exposures are more likely to result in more participants being affected, and susceptible participants experiencing either more symptoms or greater severity of symptoms.

Less obvious are those symptoms that occur as after-effects. While nausea may continue for a time after exposure, more insidious as after-effects are the often-unrecognised symptoms of postural instability, which can also persist for a considerable time after exposure. Visual after-effects involving loss of stereoscopic depth perception may also go unrecognised. These are the symptoms that can pose a safety risk to the participants and others should they leave the facility before they have recovered.

2.3 Causes of Cybersickness

The actual causes of nausea and instability remain unclear, but it is widely believed that some form of sensory conflict, resulting from conflicting cues of body position and movement, is responsible for the symptoms. A large number of factors can potentially cause such conflict, and thus give rise to symptoms. These factors may relate to the VR system, the environment generated, the task to be performed in the VE, or to individual differences in susceptibility to the effects of sensory conflict. The visual symptoms result from stressful demands on the visual system, by placing unusual demands on the cross-linkages between the processes of accommodation (focusing) and vergence (converging/diverging the eyes to fixate on near/far objects).

There are a variety of factors that influence individual susceptibility to cybersickness. These include age, gender, ethnicity, spontaneous postural sway, flicker fusion frequency threshold, and plasticity. A particularly important factor is previous experience with either the real-world or simulated task to be carried out. Previous experience with the task in the VE usually reduces symptoms due to adaptation, while experience with the real-world task but not its virtual representation is usually associated with increased symptoms. However, for practical purposes the best predictor of individual susceptibility is a past history of motion sickness or sickness in other similarly provocative situations. A history of visual problems may be indicative of higher risk for visual symptoms.

A large number of factors that may induce symptoms relate to the VR system used. These include lags resulting from transport delay or update rate, flicker, realism, field-of-view, and viewing region. Some of these factors will become less noticeable and provocative with developments in technology, so that symptoms resulting from factors such as temporal delays may occur less frequently as the technology improves.

However, the experience from flight simulators suggests that as realism increases, so cybersickness symptoms are more likely to increase.

Other factors that can induce symptoms relate to the task to be performed in the VE. The most important factor is duration of exposure, with longer exposures having a greater probability of inducing symptoms. Other factors relate to the requirements for movement, control, and navigation through the VE. Perception of self-movement (vection) can precede symptoms, and head movements during perceived self-movement are particularly nauseogenic. Greater control over interaction with the VE can reduce symptoms, as can using a method of navigation through the VE that is appropriate for the task. The type of demand the task places on the visual system can influence the occurrence of visual symptoms.

3. Adaptation

Perhaps the most powerful measure for dealing with cybersickness is adaptation, in which repeated exposures to the same VE lead to the diminution and eventual disappearance of symptoms for most participants. Adaptation is almost always specific to the particular VE. Previous research indicates that distributed exposures of short duration are more effective in facilitating adaptation than the more concentrated exposure of long duration. One problem with achieving adaptation is that it is negatively related to after-effects, so that typically as nausea during exposure decreases so instability following exposure increases. This occurs because following exposure the individual must then re-adapt to the real-world environment. Thus in the interests of safety, postural stability must still be checked following exposure even if the individual reports no symptoms. Another problem is that a small proportion of susceptible individuals does not adapt, but continues to experience symptoms despite continued exposure to the VE. Because recent investigations of adaptation have focused on problems of nausea and postural instability, its effect on visual symptoms is still unclear. Whether visual symptoms can be reduced with adaptation is still to be determined.

4. Issues to Consider in Minimising or Avoiding Cybersickness

A number of measures can be taken to reduce the likelihood that participants will experience symptoms of cybersickness. A number of properties of VEs have been found to provoke symptoms, and by taking these into account when designing the environment the potential symptoms can be reduced. Careful choice of the activities and tasks required of participants could also avoid stimuli that are particularly provocative of symptoms. Attention to the susceptibility of the individual participants, whether by identification of those most susceptible or by ensuring that participants are well informed and are in good health at the time of participation, can also avoid

unnecessary symptoms. Good practice with VR systems will take these measures into account.

The following recommendations are general and apply to most VEs, although their relative importance may vary from environment to environment. In general the VEs considered would not involve a moving base or any inertial forces, so that issues of attempting to match movement cues to visual cues need not be considered here. However, most of the complexity of influencing factors still remains. While the recommendations are general so that they can be applied to both current and later phases of FOCAL, where possible the recommendations are qualified for the current first phase FOCAL display. The first phase of FOCAL has a 12 foot (3.5m) radius, spherical section screen, illuminated by six Liquid Crystal Display projectors and driven by a 3 pipe, 6 CPU Onyx2, the system being provided by SGI and Trimension Systems. This system provides wide-angle, semi-immersive viewing for up to 10 participants, and has the capability for 3D projections. Control is from the console or by only one participant.

The following recommendations are grouped into those for design of the VE, those relating to activities or tasks to be performed in the VE, and those relating to individual susceptibility.

4.1 Design of the Virtual Environment

- Limit the rate of the global visual flow of the display.

High rates of global visual flow are more likely to provoke symptoms of nausea and postural instability, particularly in participants who have not yet adapted.

This is particularly important for the wide screen display of FOCAL, as rapid movement in peripheral vision can be particularly provocative of symptoms of nausea and instability. The rate that could be tolerated by most participants would depend on the particular display, and guidelines would need to be determined empirically.

- In flythroughs, minimise low altitude activities, rapid gains or loss of altitude, and unusual or aggressive manoeuvres. Low altitude flythroughs should be at low speed.

Flying at high speed close to the terrain increases the global visual flow rate so that it is potentially provocative of symptoms. Rapid changes in altitude and aggressive manoeuvres would be provocative in a real-world situation, and are similarly so when they are portrayed in a VE.

Because these activities would increase the global visual flow rate, they should be limited for FOCAL's wide screen display. The extent to which they should be limited

would depend on the acceptable global visual flow rate, which remains to be determined.

- Do not reset or freeze a moving display during a task.

Resetting or freezing a moving display can result in markedly conflicting sensory cues, which may provoke symptoms in participants.

The effects of abruptly resetting the moving display would be increased by FOCAL's wide screen.

- Limit the rate of movement in displays that induce perceptions of self-movement.

Vection, or the perception of self-movement through the VE, has been found to precede symptoms of nausea and instability. Greater experienced vection is more likely to induce symptoms.

There has been little research to determine the characteristics of VEs that promote vection. Wide field-of-view displays have been more frequently reported to produce vection, and symptoms of cybersickness, but particular displays on even a small field-of-view have been reported as causing vection. Whether displays on the wide screen of FOCAL readily promote vection remains to be determined.

- Decrease the field-of-view for displays that are potentially nauseogenic.

Wide field-of-view displays are more likely to induce symptoms of nausea and postural instability. If the display depicts rapid or aggressive motion, limiting the field-of-view may avoid symptoms.

The current FOCAL display has options for projecting to only a section of the total screen area. This may be useful to limit the potential side effects of selected displays.

- Ensure that participants are able to view the display from within the viewing region.

By observing the display from within the viewing region, participants are able to see undistorted depictions. Viewing distorted displays from outside the viewing region may result in nausea and instability from conflicting cues, or in visual symptoms. For some displays it may be necessary to limit the number of participants to ensure that all are within the viewing region.

Currently FOCAL can comfortably accommodate up to ten participants for group viewing. However, not all will be viewing from the optimum central viewing position, and for participants viewing from closer to the side of the screen there could be some distortion. To keep this within acceptable limits, particularly for 3D displays, the

content of the display needs consideration. Empirical investigations and experience with the facility should clarify this issue.

- Allow the participants a reasonable degree of control over their movement through the virtual environment.

In flight simulators pilots have greater control over the simulated movement, and experience fewer symptoms. In a VE a balance must be found between too little control, and too much control over detailed movement. For inexperienced participants, too much control can result in erratic movements that are also nauseogenic. The ideal is simple, streamlined control.

Currently FOCAL allows for control from the console, or limited control by one participant. Because this increases the risk of symptoms for the other participants, the previously listed recommendations become more important.

- The method of movement through the virtual environment should be chosen carefully to reduce sensory conflict.

In some cases, choosing an apparently realistic method of movement through a VE may produce a situation of subtle conflict. This is comparable to flight simulators in which greater realism produces greater sickness, as not all conflict in cues can be avoided and less obvious disparities are not so easily detectable. An example from the virtual reality literature is given by the use of an exercise bicycle to move through a simulated environment, a method that reproduced some sensory cues but not all, and was quite nauseogenic.

Currently the methods of movement through a VE generated in FOCAL are limited, but this issue may become more important as FOCAL acquires extra technologies.

- For stereoscopic displays, ensure that the eye separation and, if applicable, vergence angle are set to avoid eyestrain.

Inappropriate settings can place stress on the visual system, and result in visual symptoms following exposure. In more extreme cases the individual may find it difficult to fuse the two separate images of the stereoscopic display, with resulting symptoms of eyestrain. Eyestrain can also be produced when the projectors are not correctly aligned.

For the wide screen FOCAL display the virtual eye separation, and sometimes the vergence angle, must be set separately for each software package. Setting a larger value for virtual eye separation may give a more dramatic 3D effect, so that this must be traded off with the potential for visual stress. Determining appropriate values remains an empirical question, and will need investigation for the applications to be used.

4.2 Activities or Tasks in the Virtual Environment

- Exposure time for moving displays should be limited until adaptation has occurred.

Longer exposures to moving displays are more likely to induce symptoms, although this effect also depends on the rate of global visual flow. The faster the rate of visual flow, the shorter the exposure time should be. It has been suggested that overall exposure to moving displays be limited to no more than two hours.

Intended exposure times for displays on the FOCAL wide screen will vary depending on the purpose of the application, and the overall amount of movement displayed. Recommendations for exposure times, as for rates of visual flow, must be determined empirically for given types of application.

- Have frequent breaks if a given display or scenario is likely to produce symptoms.

The use of frequent breaks will allow for recovery and may avoid symptoms. It will also facilitate adaptation. Should participants notice any symptoms, particularly during initial exposures to a given display, they should immediately have a break from the display or scenario.

- Tasks that require high rates of linear or rotational acceleration should be avoided or kept brief until individual has fully adapted.

High rates of linear or rotational acceleration may be nauseogenic in the real world, and are more so in a VE when some conflict of sensory cues is inevitably present.

The wide screen of FOCAL would increase the likelihood that high rates of acceleration, like high rates of flow, would produce symptoms of nausea or instability.

- Have participants seated while viewing moving displays.

Moving displays that induce vection are also likely to induce symptoms of nausea or instability. A degree of postural restraint, such as provided by firm seating, can reduce the likelihood of symptoms, particularly as preventing instability may help prevent nausea as well.

The FOCAL laboratory is provided with supporting chairs with headrests, and use of these is recommended for viewing moving displays.

- Minimise tasks or activities that require participants to move their heads while viewing a moving display.

Head movements during depicted self-movements can be highly nauseogenic. Thus avoiding head movements can avoid the symptoms. Use of a headrest while seated can ensure that the head position is steady.

The FOCAL wide screen cannot be viewed in total without turning the head from side to side. This is usually a less nauseogenic movement than, for example, bringing the head forwards during apparent rotational self-movement. The use of the headrests during a more rapidly moving display will avoid forward and backwards movements of the head. Because head tracking is not provided, moving the head while viewing a 3D display can alter perspective but not in a predictable manner. Inexperienced participants may need to be warned of this.

- Minimise tasks that require visual tracking of rapidly moving objects in stereoscopic displays.

Because they disrupt the cross-links between the accommodation and vergence systems of the eyes, stereoscopic displays make greater than usual demands on the visual system. If in addition the eyes are required to focus on a rapidly moving target, they may either fail to fuse the two stereo images, with corresponding performance difficulties, or they may partially adapt and produce symptoms of visual stress. This is most problematic with visual tracking of objects rapidly moving from apparent near to apparent far distance. Participants may then experience eyestrain, blurred vision, loss of stereoscopic vision, and headaches.

This could be recommended as a general caution for the FOCAL wide screen display. Just how much tracking of moving objects remains acceptable will need to be determined empirically.

4.3 Reducing Individual Susceptibility

Individuals who are more susceptible to symptoms in VEs usually experience symptoms in a variety of provocative situations. Thus recommendations relating to susceptibility are relevant for most VEs, regardless of the VR system used. The following recommendations are general, but also apply to the current FOCAL system.

- Check whether the individual participants are highly susceptible to symptoms.

Some individuals are much more susceptible to motion-sickness-like symptoms than others. With anyone who reports a history of motion sickness, or sickness provoked by visual displays, more care should be exercised. Individuals who have had previous visual problems may be more at risk for visual side effects when using stereoscopic displays.

For experimental studies in FOCAL, a Screening Schedule has been designed to detect participants who may be at risk of symptoms, and to screen out temporarily those

individuals who are not in their usual state of good health, and so may be temporarily more susceptible (see next recommendation). Use of a screening schedule could be recommended for all participants before their initial exposure to moving displays on the wide screen.

- Individuals should not participate in the virtual environment if they are not in their usual state of good health.

Individuals are more susceptible to cybersickness if they are unwell, suffering from sleep loss, hangover, or have had a recent illness or vaccination. In addition, factors such as these that can promote symptoms have been shown to have an additive effect, thus significantly increasing the probability of symptoms in those who are not usually susceptible.

For FOCAL it is recommended that individuals do not view moving displays on the wide screen if they are suffering from one of the following:

- head cold, influenza, sinusitis or other respiratory infection
- ear infection
- middle ear disorder
- any acute infection
- recent vaccination
- recent severe illness
- sleep loss
- marked fatigue
- hangover
- upset stomach (from any cause)
- taking current medication that could cause nausea or dizziness
- eyesight problems such as blurred or double vision
- epilepsy or susceptibility to fits

Any participants who are pregnant should be alerted to possible greater susceptibility to symptoms of nausea or instability.

- Individuals with no previous experience of the virtual environment or scenario are at most risk.

With continued experience of a particular VE most individuals will adapt to it. Until they do they are more susceptible to symptoms than those who have already adapted. Therefore it is recommended that novice participants be screened before viewing potentially provocative displays, such as those depicting high rates of visual flow.

- Participants should be informed of potential adverse effects, particularly delayed onset symptoms such as after-effects, and be advised that they should allow for a recovery time following participation.

If individuals are aware that they might experience symptoms, they can determine when they may need a break during participation. They will also be aware of the need to allow for a possible recovery time before engaging in real-world activities that may place them and others at risk. The latter is an important safety measure.

- Ensure that participants are not suffering from symptoms of postural instability before they leave to resume normal activities.

Symptoms of postural instability may persist for some time after participation in a VE. Individuals themselves may not be aware of these symptoms, so they should be screened with a simple static posture test before leaving. This is particularly important if they are likely to undertake activities such as driving.

A simple test of postural stability that can be given before and after exposure is:

  - Record the time till the first stance break of standing on one leg with arms folded and eyes closed. There should be no difference in the times recorded before and after exposure to the display. A noticeable decrement in performance indicates that the individual should not undertake activities such as driving until they have fully recovered their stability.

- Promote adaptation as it gives the strongest protection against cybersickness.

Repeated short duration exposures are more effective in promoting adaptation than longer intensive exposure. The shorter exposures are less likely to produce symptoms in unadapted individuals, and absence of symptoms facilitates speedier adaptation. If individuals will need to participate in potentially provocative environments, then an adaptation schedule should be arranged.

For FOCAL, early experimentation will determine whether adaptation training will be needed for planned applications.

- Participants should be considered on an individual basis for adaptation programs.

Different individuals adapt at different rates, so that an adaptation program may need to be tailored to suit the individual. More susceptible individuals usually adapt more slowly, and may need shorter duration exposures for their adaptation program in order to avoid persistent symptoms.

- When there are several participants, any that experience symptoms should end their participation.

Symptoms may be "contagious" or result from susceptibility. Thus one individual experiencing symptoms can affect others in the group.

- Medication may be useful for some individuals who are highly susceptible to motion-sickness-like symptoms and who are unable to adapt.

Motion sickness medications are also effective against the nausea of cybersickness, and may be useful if continued participation is important.

5. Summary and Conclusions

It is possible to reduce the incidence or severity of side effects on participants in VEs. This can be achieved by careful design of the VE and of the activities and tasks to be performed in it. A number of factors that are known to induce symptoms of nausea and postural instability can be modified, and tasks and activities can be chosen to minimise both these symptoms and those of eyestrain. Measures can also be taken with the participants themselves. Highly susceptible participants can be identified and suitable precautions taken. Ensuring that participants are informed, in their usual state of good health, and enabled to adapt to the VE, can reduce symptoms of cybersickness. Perhaps the most effective measure in reducing individual susceptibility is in facilitating adaptation to the VE and its associated activities. While more specific measures can be investigated, consideration of the issues above can avoid or minimise symptoms and thus improve performance.

For the current FOCAL wide screen facility only general recommendations can be made at this stage. More specific recommendations will be possible after some planned experimental tests, so that estimates can be determined for limiting visual flow rates, allowable distance from the centre of the optimum viewing region, virtual eye separation settings, and exposure times for either moving or stereoscopic displays. Empirical tests can also determine whether a substantial proportion of individuals is likely to be susceptible to symptoms in planned applications for FOCAL, so that measures such as adaptation schedules can be pursued when necessary. If investigations indicate that side effects in FOCAL will be a problem for many individuals, then some design recommendations for reducing symptoms, taken from the research literature, could also be investigated. In the meantime, attention to the general recommendations given in this report should avoid symptoms or reduce their incidence.

6. Reference

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19. ABSTRACT

For some individuals participation in virtual environments (VEs) can result in side effects, including symptoms of nausea, disorientation, postural instability or eyestrain. The incidence and severity of symptoms are influenced by a number of factors related to the design of the VE, the task being performed, and the susceptibility of the participant. Thus taking these factors into account when designing the VE and tasks, and specifying what is required of participants, can reduce side effects. This report lists the relevant factors, and makes general recommendations to ensure that side effects in VEs are avoided or minimised. Particular consideration is given to the wide screen display of the Future Operations Centre Analysis Laboratory (FOCAL), where factors needing empirical investigation are identified.